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## Firm Capabilities, Competition and Industrial Policies in a History-Friendly Model of the Computer Industry

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**FIRM CAPABILITIES AND COMPETITION AND INDUSTRIAL POLICIES IN A  
"HISTORY FRIENDLY" MODEL OF THE EVOLUTION OF THE COMPUTER  
INDUSTRY**

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## 1. INTRODUCTION

Over the past decade industrial organization economists and scholars of business organization have come to recognize more clearly than before the often very great differences among competing firms in the capabilities they have to do various things, and the central role these capability differences play in determining the winners and losers in industrial competition. A number of scholars writing and teaching in the field of business strategy have argued that a central aspect of a firm's thinking about strategy ought to be the kinds of capabilities it needs in order to succeed in competition, and effective ways to develop or acquire those capabilities. Increasingly it is being recognized and argued that the key capabilities in question often are dynamic capabilities, capabilities that enable a firm to continue to innovate effectively and to take advantage of its continuing innovation.

This view of relevant firm capabilities, and the appropriate focus of strategic thinking in firms, clearly does not apply to firms in all industries. But it does seem right for firms in industries where innovation is a central aspect of competition. This view of competition, of course, is «Schumpeterian». And industrial organization economists increasingly have come to recognize that Schumpeter's theory of what competition is all about is much more appropriate than neoclassical views of competition in a wide range of industries, where R<sup>and</sup> D spending is significant.

They also have come to recognize that in such industries the phenomena of first mover advantage, or dynamic increasing returns more generally, may be very important. Firms that

initially get a lead may be able to push off from that early lead to establish a position that is close to unchallengeable. Dynamic increasing returns may exist on the «supply side», as firms that get an early lead in product design and a large early share of the market can use their revenues to invest in more R and D than their competitors, and increase the advantages that their products hold over those of competitors. There also may be dynamic increasing returns on the demand side, if old customers tend to return to their original suppliers for their next purchases, or if there are bandwagon effects. Under these conditions, competitive process may relatively quickly destroy competitive industry structure. This problem of course, raises some major issues of public policy in the field of anti trust, and in other areas.

In this paper, we explore some problems that industrial policy faces in industries characterized by dynamic increasing returns on the basis of a "history-friendly model" of the evolution of the computer industry.

The «history friendly» models <sup>1</sup> we are developing are models that attempt to formalize the verbal appreciative theories about the major factors explaining the particular pattern of evolution of an industry or technology put forth by empirical scholars of that industry. Thus these models tend to incorporate more industry specific details than is customary of models built by economists.. Since the logic of many verbal explanations for particular patterns of industry and technology evolution, or coevolution, involves non linear dynamics, our history friendly models take the form of simulation models.

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<sup>1</sup> These models are in the tradition of evolutionary models (Nelson-Winter,1982; Nelson,1995).

But while the early models we are building are tailored to particular industries, we are interested as well in generalizations that can be made that cut across industries, and in identifying key clusters of structural variables that seem naturally to group industries. Thus our research program is very much in the spirit of traditional Industrial Organization. And while to date our focus has been largely on trying to understand observed patterns, we also are very much interested in what these models can tell us about the efficacy of economic policies.

Our first history friendly models have been of the evolution of the computer industry and computer technology. Here, virtually all appreciative theoretic accounts have highlighted dynamic increasing returns of one form or another. While different authors have placed the emphasis in different places, our own analysis, which was sharpened greatly by our building and running a formal model, shows clearly that at least two different kinds of dynamic increasing returns play key roles in the history of the industry. One is increasing returns in a firm's efforts to advance its product and process technologies. Firms that are initially successful learn from their past successes and, because technological success generally leads to greater sales and profits, have the funds to further expand their R and D. efforts. The other is increasing returns on the marketing side. For a variety of reasons, customers who buy a particular brand of computer one time tend, other things equal, to buy that same brand when they expand their capacity or replace their old equipment. However, this latter tendency was much stronger in the era of mainframe computers than in the era of personal computers, to anticipate the history that we will recount briefly in Section 2.

The result of these dynamic forces was, of course, the rise of IBM as a near monopolist in mainframes. On the other hand, IBM was not able to transfer its monopoly position to personal computers. Our simulation models suggest that, given the structure of dynamic increasing returns, this pattern was nearly inevitable (although the way IBM entered the PC market certainly militated against its achieving a durable market dominating position there). If IBM had not reached dominance in mainframes, some other firm would. The interactive operation of those two different kinds of dynamic increasing returns virtually guaranteed that a dominant firm would emerge. And that dominant firm would have had trouble extending its monopoly into PCs because the absence there of a strong customer lock in effect.

Could public policies have changed these patterns? This is the question we explore in this paper. We do not address directly issues related to the desirability of industrial policy. Rather, we explore the efficacy problems that policy faces in dynamic environments. How does policy affect industry structure over the course of industry evolution? Is the timing of the intervention important? Do policy interventions have indirect and perhaps unintended consequences on different markets at different times?

We focus on three sets of policies: antitrust, interventions aiming at supporting the entry of new firms in the industry and public procurement of totally new products. The reasons for examining antitrust are straightforward. It is commonly considered to be the main instrument to curb monopoly power and in the history of the computer industry the discussion on the actions of antitrust authorities figure prominently.

The focus on interventions favoring the entry of new firms stems from the recognition of the crucial role of entrants in spurring competition, in opening up new markets and in generating new technologies. Lack of new entrants is often considered to be one of the possible explanations of the failure of the European industry to compete successfully with the USA in the computer industry as well as in other high technology industries. More generally, policies supporting entry have become one of the favored tools of industrial policies in Europe, both for promoting industrial growth and for raising market contestability.

Finally, in the history of high technology industries, public procurement in favor of firms developing totally new products (particularly in the United States) has been quite relevant in fostering high rates of technical change.

However, it is a legitimate question to ask whether and to what extent such policies can be successful in industries characterized by dynamic increasing returns, especially if the dynamic returns are generated by multiple sources. Are either antitrust or the promotion of entry sufficient to contrast the emergence of a monopoly? How big should the interventions be and at what time should they act? To anticipate some of our results, if strong dynamic increasing returns are operative, both through technological capabilities and through customer tendency to stick with a brand, the results of our simulations show that there is little that anti-trust and entry policy could have done to avert the rise of a dominant firm in mainframes. On the other hand, public procurement played a role in affecting market structure and concentration. However, if the customer lock in effect had been smaller, either by chance

or through policies that discouraged efforts of firms to lock in their customers, the situation concerning antitrust and entry support might have been somewhat different. In the first place, even in the absence of anti trust or entry encouraging policies, market concentration would have been lower, albeit a dominant firm would emerge anyhow. Second, anti trust and entry encouraging policies would have been more effective in assuring that concentration would decrease. The leading firm would continue to dominate the market, but its relative power would be reduced.

The paper is organized as follows. In section 2 we briefly discuss the history of the computer industry. In section 3 we present the model. In section 4 we discuss history replicating simulations, while in section 5 we compare the effects of alternative – extremely stylized – policy interventions. In section 6 we draw some final conclusions.

## **2. THE EVOLUTION OF THE COMPUTER INDUSTRY AND COMPETITION POLICY**

Given space constraints, we can recount only a stylized history of computer technology and the computer industry, drawing from Flamm (1988), Langlois (1990), Bresnahan and Greenstein (1999), and especially Bresnahan and Malerba (1999).



The history of the computer shows continuous improvements in machines that serve particular groups of users, punctuated from time to time by the introduction of significant new component technologies which not only permit the needs of existing users to be met better, but also open up the possibility of designing machines that serve new classes of users whose needs could not be met using older technology. In the United States these punctuations were associated with the entry into the industry of new firms, and these new firms almost always were the first to venture into the new market. However, this happened to a significant lesser degree in Europe, and hardly at all in Japan.

The evolution of the industry divides rather naturally into four periods. The first began with the early experimentation with computers which culminated in designs sufficiently attractive to induce their purchase by large firms with massive computation tasks, as well as by scientific laboratories. This opened the era of the mainframe computer. The second era began with the introduction of integrated circuits and the development of minicomputers. The third era is that of the personal computer, made possible by the invention of the microprocessor. We now are in the era of networked PCs and the increasing use of the Internet.

During World War II and the years just after, Governments in several countries funded a number of projects with the aim of developing computers useful for Governmental purposes. In the late 1940's and early 1950's a number of companies, in Europe as well as in the United States, began investing their own funds hoping to develop a computer sufficiently attractive to win the market of scientific laboratories, large firms, and other organizations who had large-

scale computation needs. The early 1950's saw the entry into the industry of IBM--then a major punched-card and tabulating machinery company, but with significant capabilities in electronic computing derived in good part from government R and D contracts--and the rest of the Bunch (Burrows, Univac Rand, NCR, Control Data, Honeywell), as well as GE and RCA. These companies differed in the strategies they took, and in their success in developing machines that would sell at a profit. By 1954, with the introduction of the 650, IBM began to pull ahead of the Bunch, and with the introduction of the 1401 in 1960, came to dominate the world market for accounting machines.

IBM dominated not only in the American market, but in Europe, and Japan. A small-scale domestic industry was able to hold on in Europe, and later in Japan, only by virtue of a combination of government subsidy, a guaranteed government market, and protection.

Component technology improved greatly during the the mainframe era, and transistors gradually replaced vacuum tubes as the basic circuit elements. These developments enabled significant improvements in mainframe performance, and some reduction in cost. In the early 1960's IBM introduced its 360 family of models, and seized an even larger share of the mainframe market.

The invention and development of the integrated circuit enabled even further improvements in mainframe computers and also reduced barriers to entry in the mainframe industry, thus stimulating the entry of new competitors to IBM. However, integrated circuits not only permitted large computers to be made even more powerful. They opened the

possibility of designing computers that had a considerable amount of power, but could be produced at a much lower cost than mainframes. DEC's PDP8, the first minicomputer, was produced in 1965. Minicomputers opened up a new demand class which had not been tapped by mainframes, which included medium-sized research laboratories, manufacturing firms, and some small businesses.

In the United States new firms, like DEC were the first into the new minicomputer market; these new firms seized and held a significant share of that market. IBM lagged in getting into minicomputers, and never achieved there the dominance it achieved in the mainframe market. While the availability of integrated circuits provided an opportunity for European and Japanese firms to get into the minicomputer market, as in the earlier case with mainframes, firms in Europe and Japan lagged. American firms took a considerable fraction of the minicomputer market in Europe and Japan, and domestic firms held on there only through a combination of subsidy, and protection.

The introduction of the microprocessor marked another punctuation in the history of the industry. Microprocessors enabled significant improvements in mainframe and minicomputer designs. However, their most important impact was to permit the design of reasonably powerful computers that could be produced at quite low costs. Personal computers opened up a new demand class which had not been touched by mainframes and minicomputers: small firms, and personal users.

As in the case of minicomputers, in the United States new firms entered the industry aiming to serve the new personal computer (PC) market: these included prominently specialized PC design and manufacturing firms (such as Apple, Commodore, Tandy, and Compaq). Established mainframe and minicomputer producers were slow in seeing the new market and the needs of users in that market. Interestingly, when IBM did get into PCs, it did so with external alliances: Microsoft for operating systems software, and Intel for microprocessors. IBM did manage to seize a significant fraction of the personal computer market, but never was as dominant there as it had been in mainframes. And, of course, in recent years IBM's share in PCs has eroded significantly.

A striking characteristic of the firms producing personal computers is that they are primarily assemblers, buying most of their components on the open market. Also, most of the software for personal computers is developed and supplied by software specialists. This is in sharp contrast with mainframe production, particularly in the early and middle stages of the industry. Thus IBM not only designed and produced most of the critical components for its mainframes, but also wrote most of the basic software. For a time, IBM also designed and produced a significant fraction of the integrated circuits that were employed in its mainframes. In minicomputers there was, from the beginning, more vertical specialization than in mainframe production, with most minicomputer companies buying their integrated circuits, and a number of other key components, on the open market. But personal computers have seen even more vertical disintegration.

As noted, the advent of personal computers led, in the United States, to the birth of a number of new firms, several of which turned out to be very successful. Just as in the case of minicomputers, in Europe and Japan in contrast few firms entered. And, except where there was heavy government protection or subsidy, American firms have come to dominate foreign markets for personal computers.

There are many interesting challenges for history-friendly modeling in the history recounted above. In a previous paper (Malerba-Nelson-Orsenigo-Winter,1999), we analyzed the pattern of development of industry structure. A second challenge is provided by the progressive vertical disintegration of the computer industry, and in particular by the sharp increase in specialization that has marked the era of personal computers. Still a third challenge is to explain the significant differences between the United States on the one hand, and Europe and Japan on the other, with respect to the ability of new firms to take advantage of "competence destroying" technological changes.

In this paper we focus on a somewhat different issue. We discuss some problems concerning the conduct and the effects of alternative policy interventions which have or might have influenced the evolution of the computer industry. The policy interventions that will be discussed in this paper concern antitrust and entry support. On the contrary we will not discuss military policy, which was quite relevant in the early history of the industry. As far as antitrust policies are concerned, during all the history of the industry they were anti-IBM both in the United States and Europe. In the United States antitrust policies forced IBM to unbundle mainframe hardware from software and to behave less aggressively with respect to Amdahl and

PCMs. In Europe on the contrary they were highly tolerant of national champions in their anti IBM role. Entry support policies have been at the center of the policy debate, particularly in Europe, because entry has played a major role in the history of the industry. This debate has discussed how to foster entry in order to improve national competitiveness and, to a lesser extent, to increase competition within concentrated segments such as mainframes.

Before discussing these policies, we are going to present the basic structure of the model.

### **3. THE MODEL**

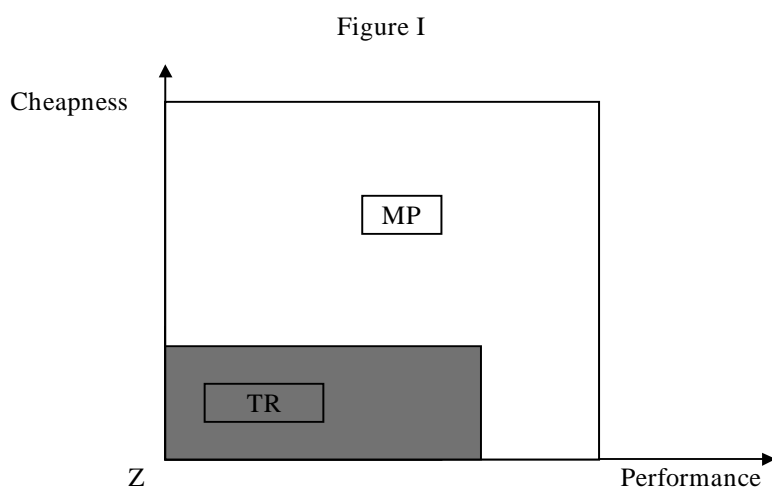
In this section we lay out the basic model. Given the nature of complex simulation models, it is impossible to present all the details of all the equations, without befuddling the reader and obscuring the basic logic of the model. We have tried, therefore, to lay out in transparent form what we regard as the gist of the model. Interested readers may obtain a full copy of the simulation model by writing to the authors.

#### *3.1 The Topography*

In this model we consider a single stylized episode of the sort under consideration. At the start of the episode, there is a single component technology, which we will call "transistor" technology, which has the promise of enabling useful computers. Later, a new component technology, which we will call "microprocessors," comes into existence. The potential

purchasers of computers value two attributes. One is the "performance" of the computer. The other is its price, or "cheapness." The desirability of any computer design can be summarized in terms of how it rates in those two dimensions of Lancaster attribute space. By a useful computer we mean one that meets threshold requirements of potential purchasers. More on this shortly.

Each of the component technologies is associated with outer limits on what computers incorporating them can achieve in the two relevant dimensions. For analytic convenience, we have treated those technological constraints as defining a rectangular box. Thus in Figure I the two boxes depict the set of technological characteristics that potentially can be achieved in computers designed around transistor, and microprocessor, component technologies. Note that the use of microprocessors permits computers to be designed that are better than transistor-based computers regarding both performance, and cheapness. However, the most dramatic improvement that is permitted by the incorporation of microprocessors lies in the cheapness direction.

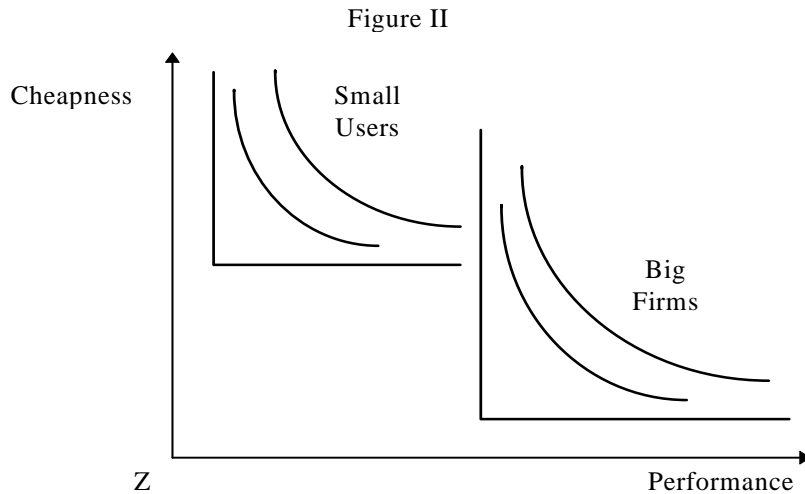


Those outer limits of what is feasible under the two technologies are "potentials." The potential is not achievable, however, without significant investment of resources in research and development, and requires learning from experience. The first efforts of a new firm trying to design a computer using transistors, or (later) microprocessors, will only be able to achieve a design characterized by point Z (for zero experience). We will specify the dynamics of design improvement built into the model in Section 3.2.

On the demand side, there are two quite separate groups of potential customers. One group, which we will call "large firms" greatly values "performance" and wants to buy "mainframes". The second group, which we will call "individuals, or small users" has less need for high performance but values "cheapness". They provide a potential market for "personal computers", or PCs.

Each of our two user groups requires a minimum level of performance, and cheapness, before they can be enticed to buy any computers at all. Once threshold characteristics are reached, the value that customers place on a computer design is an increasing function of its performance, and its cheapness. In Figure II we depict the preferences of "big firms" and "small users" respectively. The difference in the demands of the two user groups, that we specified above, is reflected in both the difference in threshold requirements, and in the indifference curves.





If one overlays Figure II on Figure I, one can note that even if computers achieve the outer limits permitted by transistor technology, the threshold requirements of small users will not be met. Thus the design of computers that can successfully enter the personal computer market depends on the availability of microprocessors.

The "indifference curves" of Figure II depict designs of equal value or "merit" in the eyes of the two customer groups. We assume that higher computer merit translates into more computers bought by customers. We shall develop the details in Section 3.3.

The above discussion indicates clearly some of the broad outlines of what one would expect to see in a simulated industry history, and also points to some of the matters that need to be treated in specification of the dynamics. Assuming that there is some way that firms can obtain funds, computer technology will start out at Z. Over time, and with R&D spending, computer designs will improve until ultimately they crack through the threshold requirements of the "mainframe market." Then firms that have achieved threshold-meeting designs, will

begin to make sales. As computers improve, sales will grow. The introduction of microprocessors will open the potential of meeting mainframe demands even better, and of designing machines that will sell on the PC market. Firms that try to pursue those possibilities will need some funding in order to do that because, initially at least, no one will buy their wares. However, ultimately one would expect that microprocessor computers would take over the mainframe market, and be able to tap the new PC market.

We now turn to explicit dynamics.

### *3.2 Innovation Dynamics, Firms' Finance, R&D, Advertising and Pricing Decisions*

When transistors, and later microprocessors, come into existence, firms have to learn how to design effective computers using these new components. Firms gradually develop competence in using the new technology as a result of the R&D investments they make, and the experience they accumulate. Our model of firm learning is meant to capture significant elements of the "dynamic competence" theory of the firm that has been developed by Winter (1987), Dosi and Marengo (1993), and Teece, Pisano, and Shuen (1992).

In the model, firms are represented by sets of technological and marketing competencies that are accumulated over time, and by rules of action. The focal competencies in the model are design capabilities: by building incrementally on their past achievements and by accumulating experience, engineers produce successive generations of computers with superior cost/performance attributes. Other actions reflected in the model of the firm concern

the pricing of products, R&D and advertising expenditures, the adoption of new technologies and diversification into new markets. There is no explicit representation of production *per se*, or of investments in capacity. It is assumed that the requisite production capabilities can be hired at a price per computer that reflects the "cheapness" attribute of the design.

Our model also is designed to incorporate the fact that in this industry, and in a number of others, a considerable period may go by after a firm starts trying to operate in a new technology before it is able to sell any product, if it ever achieves that. At the start it must have external financing.

Thus at the beginning of our episode, with the introduction of transistors, we assume that there are a number of firms, endowed by "venture capitalists" with an initial budget to spend on R&D, who hope to exploit the new technological opportunities. All firms start with the same initial design capabilities, depicted by Z in Figure 1, and perhaps interpretable as the design characteristics that have been achieved by experimental computers that are in the public domain. Firms start off with different, randomly selected initial budgets, IB, which are used to finance an R&D project, the length of which is fixed and equal for all firms. During this initial time, in each period firms spend a constant fraction of their budget on R&D. If the funds are exhausted before a marketable design is achieved, firms exit.<sup>2</sup>

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<sup>2</sup> Albeit different in basic concepts, structure and overall framework, this part of the model is similar to Jovanovic (1982) model. Firms start with an uncertain environment and only learn through experience –trial and error in the market- if this endowment is valuable or not. We are grateful to a referee for showing us this point.

Design outcomes are influenced by firm-specific strategies represented by choices of search direction in the capabilities space, but also by latent technological opportunities. Firms are born with different, randomly selected trajectories of technological improvement along the two technological dimensions, costs and performance. In order to capture - in an extreme form - the notion that competencies cannot be changed rapidly and costlessly, in the model it is assumed that this trajectory is firm-specific and time-invariant. Thus, after the initial period, the firms in the industry will be doing different things, and will be achieving computer designs of different characteristics.

As firms spend on R&D, they accumulate technical competencies. Technical progress is represented in the model as a change in a computer design along the two technical dimensions, generated by the application of these firm-specific competencies. Technical competencies are represented as a stock that grows over time as a result of R&D expenditures. One can think of competencies as reflecting the shared experience of two types of “engineers”: cost-oriented and performance-oriented engineers. Their mix is defined by the technological trajectory that characterizes each firm. As time goes by, firms hire new engineers, maintaining constant at any period the proportion between the two types and hence the trajectory of advance.<sup>3</sup>

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<sup>3</sup> As we will see later, the assumption that technical competencies grow over time is valid only within a given market and technology. With the emergence of a new technology or a new market, the accumulated competencies of existing firms decay in various ways.

In each period  $t$ , R&D expenditures,  $R_t$ , are used to pay the stock of engineers of last period,  $R_{t-1}$ . For each of the two design dimensions, if the share of total R&D allocated to one particular type of engineers  $R_t^i > R_{t-1}^i$ , then the surplus is invested in hiring new engineers, at a given cost  $c_{eng}$  per engineer. Conversely, if  $R_t^i < R_{t-1}^i$ , then 10% of the engineers is fired. If  $R_t^i < 0.9 R_{t-1}^i$ , the budget  $B$  is used to pay for the difference.

From period to period, the quality of the design that a company is able to achieve in each relevant dimension--performance and cheapness--improves according to the following equation:<sup>4</sup>

$$1) \text{ change } X_i = a_0(R_i)^{a_1}(T_j)^{a_2}(L_i - X_i)^{a_3}e$$

The first variable,  $R$ , is the firm's R&D expenditure aimed at achieving design improvements of a particular sort, where  $i=1$  denotes performance and  $i=2$  denotes cheapness. That expenditure allows the firm to maintain a given stock of engineers dedicated to advancing computer design in the two relevant dimensions. That expenditure, in turn, is a constant fraction of its period-by-period R&D expenditures in total. The fraction reflects the firm's "bet" as to the most useful direction to proceed. As we noted, a firm's total R&D expenditure per period is a constant fraction of the total funds lent to it by its venture capital

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4 We use log linear equations whenever plausible because most economists have a good feel for their behavior and their quirks. Also, while in most cases the behavior being specified obviously relates to particular firms, to avoid clutter we do not denote that specifically.

financiers. After that initial loan is drawn down, a firm either has achieved a commercially viable design, or it is out of business.

The second variable,  $T$ , is the number of periods that the firm has been working with a particular technology, in this case transistors. For all firms that start with a technology at the same time, this second variable will be the same. However, when later in this exposition we begin to describe the evolution of computers employing microprocessor technology, firms will differ regarding the times when they get into that technology, and thus in that technology there will be differences across firms in this experience variable.

The third variable in the equation,  $L_i - X_i$ , is distance of the achieved design to the frontier. As what is achieved comes closer and closer to the limits of what is achievable, a given R&D expenditure will achieve less and less further progress. There also is a random element to what a firms achieves,  $e$ .

As indicated, if a firm runs through its initial loan before it achieves a marketable product, it simply fails. However, if a firm manages to push its design into the region where customers are buying, it is a new ball game. Now funds from revenues can be invested in R and D and in marketing.

Profits,  $\pi$  are calculated in each period  $t$  as:

$$2) \pi_t = M \cdot p - M \cdot k,$$

where  $M$  is the number of computers sold,  $p$  is the computer price and  $k$  is production cost of a single computer.

Production costs,  $k$ , are determined by the technical progress function. Price is obtained by adding a mark-up,  $\mu$ , to costs:

$$3) p = k * (1 + \mu)$$

The mark-up,  $\mu$ , is initially set equal for all firms, but it then grows over time as a function of the market share that has been achieved. In other words, as firms gain monopoly power, they (partly) exploit it by charging prices above marginal costs. Specifically.

$$4) \mu = 0.1 + 0.1 * m$$

where  $m$  is the firm's market share.

The gross margin over production costs is used to cover several things. Firms start to spend a constant fraction  $\sigma$  (15% for all firms in this version of the model) of their profits in each period to pay back their debt  $D_t$  to investors - that is to say, the initial budget capitalized at the current interest rate,  $r$ , until the debt has been fully paid back.. What is left is used to invest in R&D and in advertising.

R&D expenditures,  $R_t$ , are simply determined as a constant fraction,  $\phi$ , of what is left of gross profits,  $\pi_t$ , after the repayment of the initial budget .

$$5) R_t = \phi * \pi_t (1 - \sigma)$$

The variable  $\phi$  is time-invariant and firm-specific, although in the simulations of this paper its value has been set equal for all firms.

Advertising expenditures are considered in a very similar way to R and D expenditures, in that they produce marketing competencies that are accumulated over time. If firms do not invest, their advertising capabilities deteriorate over time - and hence the size of the advertising expenditures effect decreases, for any given amount of expenditure. Moreover, it is assumed that the effect of advertising on sales follows a logistic curve. Specifically, the model first computes advertising expenditures,  $A^*$ :

$$6) A^*_t = \delta * \pi_t (1 - \sigma)$$

Then, this value is divided by a number that defines the amount of advertising expenditures beyond which the elasticity of sales to advertising is equal to zero (i.e. the asymptote of the logistic curve). This ratio is then inserted into a logistic curve to yield the value of the variable A in the demand equation (See equation 7, Section 3.3).



The excess gross profits after debt repayment, R&D expenditures and advertising is invested in an account,  $B_t$ , that yields the interest rate,  $r$ , in each period. and is treated in this model as "reserves." These reserves will enter the model in an important way for transistor firms who have survived into the era when microprocessors have become available as an alternative component technology. We will consider what happens then in Sections 3.4 and 3.5, concerned with transition dynamics.

### *3.3 Market Dynamics*

An essential feature of the computer market is the existence of differentiated products and different market segments. The model incorporates some of these features of the demand side of the industry.

The industry is composed of different types of users who have different needs regarding the characteristics of computers. Moreover, demand behaviour is influenced by informational considerations and by the advertising efforts of producers, as well as by the actual utility of alternatives presented. "Comparison shopping" is limited. Some customers may purchase computers that are far from the best on the market at the time, simply because, viewed in isolation, those computers are worth the asking price. Finally, bandwagon and brand loyalty effects may play an important role in determining the performance of individual firms.

First of all, the demand for computers is expressed as a demand for specific product characteristics in a Lancasterian vein. Let  $p$  be the price charged for a specific computer, then denote "cheapness" by  $X_1 (= 1/p = 1/k * (1+\mu))$ , and "performance" by  $X_2$ .

Computers are demanded by two different user groups, identified as "big firms" and "individuals." They constitute, respectively, the mainframe market and the personal computer market. The choice of these two particular groups of users is due to the fact that mainframes have been mostly used by big firms, while personal computers have been sold for personal uses (at home or at work). These users differ in their threshold requirements for the attributes of cheapness and performance, with individuals having more stringent minimum requirements for cheapness but less stringent requirements for performance than do big firms. The market activity of each type is represented by independent purchasing decisions by a large number of "submarkets" of that type. Submarket buying behavior reflects the fact that computers are durable goods that deliver services over a period of time, and the demand facing producers is a demand for replacements or increments to the stock of such durables.

The number of submarkets in each main market (mainframes and PCs) is a parameter of the model. Individual sub-markets buy computers if they don't have one - either because they have never bought one before or because of breakdowns. Computers have a finite life and surely break down after  $\tau$  periods. The model keeps track of the average age,  $G$ , of the computers held by each submarket. In each period, a fraction  $G/\tau$  of the submarkets experiences computer breakdowns and becomes ready to buy new computers. Moreover, submarkets buy computers if they "see" the supply: when there are only few firms in the

market, individual submarkets may not purchase any computers. The probability of buying a computer is equal to one if there are at least  $S$  firms selling in the marketplace. When there are only  $n < S$  firms, the probability decreases proportionally.

A simple formulation of consumer preferences is the following. Consider a particular group of consumers. Define  $M$  as the “level” of utility associated with a computer with particular attributes. Then, the utility of a computer with cheapness  $X_1 = 1/p$  and performance  $X_2$  for the user class  $s$  is given by a Cobb-Douglas function with the arguments that measure the extent to which threshold requirements have been exceeded rather than the raw values of cheapness and performance themselves:

$$(7) \quad M = b_0 (X_1 - X_{1\min})^{b_1} (X_2 - X_{2\min})^{b_2}$$

where  $b_0$  is a scale parameter, and  $X_{1\min}$  and  $X_{2\min}$  are the threshold levels for cheapness and performance. If threshold requirements are not met,  $M=0$ . The sum of the exponents in the utility function operates like a sort of generalized demand elasticity reflecting performance as well as price.

Consider now some number of customer groups, say two. Let the (integer) number of computers of a particular character that potentially would be purchased by a specific group of customers (if no other competing product were offered in the market) correspond to the level of utility,  $M$ . In other words, the greater the “merit” of a machine, the greater the number of

machines that will be purchased. This way, the utility function has a cardinal interpretation and is treated heuristically as a demand curve.

After some time, some firms will succeed in achieving a computer design that satisfies the minimum thresholds required by consumers in the mainframe market and will start selling their product on the market. At the beginning, the market is small, both because the utility delivered by computers is low (the industry is in its infancy and technology has not yet progressed very much) and because many consumers may not even perceive that these products are available (or they may not even realize that computers might be useful to them). As the quality of computers increases and as more and more firms enter the market, total demand grows as a consequence of both an increase in the number of consumers and an increase in the number of computers purchased by individual groups of customers.

If there is more than one kind of computer that meets threshold requirements, our analysis of demand involves variables other than  $M$ . The appreciative story put forth by many scholars of the history of the industry to account for the sustained dominance of IBM in the mainframe market includes concepts like band wagon effects or brand loyalty (or lock in), and advertising. Thus history friendly modeling needs to bring these in.

Customers select different computer designs as a function of their relative utility,  $M_i$ , as it results from the specific mix of price and performance characteristics. However, various informational constraints, like bandwagon and brand-loyalty effects, affect customers

behavior. These are captured in a compact formulation by the effect of the variables measuring the firms' market shares and advertising.

The probability,  $P_i$ , that any submarket (individual computer buyer or group of them) will purchase a particular computer,  $i$ , is as follows.

$$8) P_i = c_0(M_i)^{c_1}(m_i+d_1)^{c_2}(A_i+d_2)^{c_3}$$

$c_0$  is specified so that the sum of the probabilities adds to one. As noted,  $M$  denotes the "merit" of a computer. " $m$ " is the market share, in terms of the fraction of total sales revenues accounted for by that computer. Note that the market share variable can be interpreted either in terms of a bandwagon effect, or a (probabilistic) lock-in of customers who previously had bought machines of a particular brand. The " $d_1$ " assures that computers that have just broken into the market, and have no prior sales, can attract some sales. " $A$ " is the advertising expenditures of the firm producing the computer. The " $d_2$ " performs here a similar role to " $d_1$ " for firms that have just broken into the market and have not yet invested in advertising.

Given that customers in a particular submarket buy a particular computer,  $M$  is the number they buy. Note the following. First, if there is only one computer that meets threshold requirements, each submarket will buy it with probability 1, and will buy " $M$ " units of it, as we asserted (assumed) earlier. Second, assume that there is more than one computer that passes the threshold. If " $c_1$ " is very high, and " $c_2$ " and " $c_3$ " are very low, virtually all the customers will buy the computer with the highest merit score. On the other hand, if " $c_1$ " is relatively

low, or "c2" and "c3" are high, a higher merit computer may be "out sold" by a rival computer that has the higher existing market share, or which has been advertised more intensively, or both.

In the absence of the bandwagon/brand loyalty effect and of advertising, the demand module would behave similarly to a standard demand curve. Demand would converge to "best value for the money", although in the limit a positive probability of survival for inferior computers always remains. Convergence is faster the higher is the parameter  $c_1$ . The consideration of brand loyalty and of the bandwagon effect changes this picture quite drastically, introducing inertia and forms of increasing returns.

### *3.4 Competition Between the Technologies, With "Locked In" Firms*

Within this model, after a number of periods have gone by, and after a number of transistor firms have successfully entered the mainframe market, microprocessors come into existence. A number of new firms start out at point "Z" in Figure 1, with funding provided by venture capitalists, just as earlier new firms had started out at that point using transistor technology. Some of these firms will fail before they get into a market. Others may succeed.

Notice that while existing transistor firms provide no "barrier to entry" for microprocessor firms who have aimed their trajectory toward the personal computer, or PC, market, the existence of established transistor firms in the mainframe market creates a significant barrier to entry. First of all, if a microprocessor firm achieves a design that meets threshold requirements in the mainframe market, that computer is in competition with existing

transistor-based computers that already have achieved higher than threshold quality levels. Second, the extant transistor mainframe producers have acquired positive market share, and have engaged in significant advertising, and that further disadvantages a newcomer. It is an open question within this model whether a new microprocessor firm can survive in the mainframe market. If not, and if extant transistor firms cannot or do not switch over to making mainframes out of microprocessors, the potential in the mainframe market afforded by microprocessor technology never will be realized.

In fact, we know that microprocessor firms did enter the mainframe market, but did not fare well there, in part because extant mainframe firms themselves adopted microprocessor technologies. Further, some of those old mainframe firms, IBM in particular, then used microprocessor technology to try to enter the PC market. Thus there are two different kinds of transitional dynamics that need to be built into this model, if it is to be "history friendly." First, we must enable firms that originally are using one technology to switch over to another. Second, we must enable firms who are in one market to try to diversify into the other.

### *3.5 Transition Dynamics*

We noted above our desire to capture in our model a number of aspects of the new understandings about dynamic firm competencies, and competence "lock-ins". We have built into the model that firm competencies are "cumulative" with today's design efforts building on what was achieved yesterday. Firms tend to get better and better at the particular things they are doing. On the other hand, it is clear that firms often have a good deal of difficulty when

they try to do significantly new things. Thus Tushman and Anderson (1986), and Henderson and Clark (1990), have documented the difficulty that firms often have in coping when the best technologies underlying their products change significantly. Quite often extant firms cannot switch over rapidly enough to counter the efforts of new firms using the new technology. Christensen and Rosenbloom (1994) have put a spotlight on similar difficulties that extant firms have had in recognizing new markets when they opened up.

In our model, existing transistor based mainframe firms are able to switch over to microprocessor technology for use in their mainframe designs, but this may be time consuming and costly for them. It is new firms that do the initial work of advancing computer design using microprocessors. The probability that an extant transistor firm will try to switch over is a function of two variables. The first is how far along microprocessor computer designs have been pushed. The second is the closeness of a transistor firm to the technological possibility frontier defined by transistor technology. The former clearly is a signal to extant firms that "there is a potentially powerful new technology out there, and we may be in trouble if we don't adopt it." The latter is an indication that "we can't get much further if we keep on pushing along the same road."

If an old transistor firms decides to switch over, it faces one significant disadvantage, but also has an advantage. The disadvantage is that the experience that got it to the forefront of transistor technology (recall Equation 1) counts for little or nothing if it shifts over to microprocessor technology. Thus in its first efforts in microprocessor computer design, it will achieve only about the average for extant microprocessor based mainframe firms. Further, it



must incur a once and for all switchover cost in order to start designing, producing, and marketing microprocessor based mainframes. However, extant transistor firms have the advantage of large R&D budgets which, with a cost, they can switch over to working with the new technology, and a stock of accumulated earnings on which they can draw to cover any transition costs.

In sum, adoption of the new technology takes place in two steps. First, a firm must “perceive” microprocessors technology. Perception is a stochastic process that depends on the current technological position of the potential adopter in relation to the technological frontier in transistors and on the progress realized by the new technology:

$$(9) \Pr_{\text{perc}} = [z_i^g + z_{\text{mp}}^h / 2]^\lambda$$

where  $P_{\text{perc}}$  is the probability of perceiving microprocessors technology,  $z_i$  is fraction of the transistors technological frontier covered by firm  $i$  and  $z_{\text{mp}}$  is the fraction of the microprocessors frontier covered by the best-practice microprocessors firm. The parameter  $\lambda$  measures the general difficulty of perceiving the new technology.

Once firms have perceived the possibility of adoption, they have to invest in order to acquire the new technology. Adoption costs ( $C_{\text{ad}}$ ) entail a fixed cost,  $F_{\text{ad}}$ , equal for all firms, and the payment of a fraction  $q$  of firms’ accumulated budget, linked to factors like the training of engineers and the like. Thus,

$$(10) C_{ad} = F_{ad} + q B_t$$

Firms whose budget does not cover the fixed costs or whose profit rate is negative cannot adopt microprocessors. Moreover, the competence-destroying nature of the new technology is captured by the notion that adoption implies that the experience accumulated on the old technology counts now much less. In the model, experience ( $T$ ) is reduced by a factor which is a parameter of the model.

Once firms have adopted the new technology, they have access to the new technological frontier and can innovate faster. However, they maintain their original trajectory.

Once an old transistor mainframe firm has switched over to microprocessor technology, it is potentially open to it to diversify by designing and trying to sell computers on the PC market. Diversification can take place only after the adoption of microprocessors. The incentive for diversification is a function of the size of the PC market, defined in terms of the number of computers sold, as compared to the mainframe market. Specifically, diversification becomes possible when the ratio between the size of the PC market and the size of the mainframe market is bigger than a threshold value, which is a parameter of the model.

The firms' old design trajectory will, in general, not be a good one to pursue if it wants to diversify into PC's. As noted, IBM diversified by setting up an entirely new division, and that is what we assume about diversification of mainframe producers into the PC market in this model.

The parent company founds a new division trying to exploit the available competencies specific to PCs, rather than to apply its own competencies to the new market.

The new division inherits from the parent company a fraction of the budget, of technical capabilities and advertising capabilities. The size of these fractions are all parameters of the model. The position of the new division in the design space is determined as the average merit of design prevailing in the PC market at the time diversification occurs. In other words, the parent company exploits “public knowledge” in the PC market and partly “imitates” PC firms. The technical progress trajectory ( i.e. the mix of engineers of the two types) is randomly re-calculated. After birth, the new division behaves exactly as a new entrant, with independent products and profits and budget.

The new divisional firm faces the disadvantage that there already are firms selling in the PC market, with designs that already exceed thresholds, positive market shares, established advertising budgets, and experience in the PC market. However, the new divisional firm does have the advantage of being able to dip into the "deep pockets" and resources of its mother firm, which can switch over to PCs a sizeable fraction of its extant R and D and advertising budgets. After the initial infusion of resources, the new PC branch firm is on its own.

#### **4. HISTORY REPLICATING AND HISTORY DIVERGENT SIMULATIONS**

This model is able to “replicate” the industry history, with a parameter setting that reflects the basic key assumptions that economists who have studied the computer industry suggested were behind the pattern that happened. We call this parameter setting the “standard set”. The details of the simulations are discussed in a previous paper and, for reasons of space, we do not discuss them here again (Malerba-Nelson-Orsenigo-Winter, 1999).

A dominant transistor-based firm (IBM) emerged relatively quickly in the mainframe market. That firm held on to its large share of the market, even when new microprocessor firms entered that market and challenged it. Part of the reason the dominant firm held on is that it shifted over to microprocessor technology in a relatively timely manner. That firm then entered the PC market, and gained a nontrivial, but not a dominant share.

The key factors that led to this pattern were assumed to be the following. First, the early buyers of IBM equipment tended to feel themselves “locked in” to IBM for upgrades, extensions, and renewal of their computer capacity, largely because of specialized software. This made entry of new firms difficult. In terms of our model, a firm that has a high market share in mainframes will, because of that, attract a significant share of new purchases. Second, by the time the new technology came along, computer design under the old technology was reasonably advanced, and the leader, IBM, responded to the availability of new technology pretty rapidly. In terms of our model, soon after the first microprocessor firms enter the mainframe market, the dominant transistor firm in that market switches over to microprocessors. Third, IBM's massive resources enabled it quickly to mount an R&D and advertising effort sufficient for it to catch up with the earlier entrants into the PC market.

However, because the PCs produced by a number of other companies were compatible with the software used by IBM PC's, there was no specific lock-in to IBM. And within the class of IBM compatibles, customers were quite sensitive to the merit of the computers being offered, particularly to price. In terms of our model, in the PC market the coefficient on quality was high, and the coefficient on specific market share was low.

After a "history friendly" replication base case had been achieved, we modified the value of the parameters we identified as corresponding to the fundamental causal factors of the observed history, in order to see if those changes produced quite different patterns of evolution. Thus, we reduced the coefficient on market share in the demand equations for mainframes, to see if this would damp down the tendency of a dominant firm to emerge, and hold on in the face of new stringent competition. Second, firms using microprocessor technology entered the mainframe market earlier, before a dominant firm has emerged. Third, transistor firms were more sluggish in shifting over to microprocessors, and it was more costly for them to do so. Fourth, demand in the PC market was more sensitive to advertising, and less sensitive to computer quality, so that a deep-pockets company diversifying into PC's from mainframes had a chance of quickly grabbing a large share of the PC market. Results of the simulations were consistent with our expectations.

Being satisfied that the structure and the parametrization of the model captures the basic logic behind the evolution of the computer industry, we are now confident to use this apparatus to carry on further experiments and counterfactuals to analyze the problems and the effects of alternative policy interventions.

## **5. COMPETITION AND INDUSTRIAL POLICIES IN DYNAMIC MARKETS: ANTITRUST, ENTRY SUPPORT AND PUBLIC PROCUREMENT**

In this paper two broad groups of policies are going to be discussed: antitrust and entry support. Antitrust policies have the aim of reducing the high level of concentration in the market, while entry support policies have the objective to increase contestability and variety. We will examine them in their effects on market concentration, price and technological change. Results refer to 100 runs.

### **5.1. Antitrust policies**

In our model antitrust authority (AA) intervenes when the monopolist reaches a share of 75% of the market<sup>5</sup>. It acts by breaking the monopolist in two. The two new firms originating from the old monopolists have half of size and resources of the previous monopolist: budget, engineers, cumulated marketing expenditures (and thus also bandwagon effect). They maintain however the same position in terms of product attributes (cheapness and

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<sup>5</sup> Given the feature of our model, the 75% share could be set higher or lower without changing the features of the intervention. In fact, the monopolist in few years reaches a share between 85% and 90% of the mainframe market and does not falls below it in the course of the whole simulation.

performance), experience and technology of the previous monopolist.<sup>6</sup> The two new firms differ only in terms of trajectory: one of the two has the monopolist trajectory, the other a trajectory chosen at random.<sup>7</sup>

We have tested a very rapid AA intervention or a very late one. In one case antitrust intervenes very soon, 1 year after the first firm has reached a share of 75% of the market. This is a very unrealistic run, because most of the time AA breaks the first entrant. But we have used it as an extreme case. In other cases AA intervention is not immediate (5 years), late (10 years) or very late (20 years).

Results are shown in Table 1 for the Mainframe market, where the Herfindahl indexes for the various cases are compared. When AA intervenes extremely early, the market becomes concentrated again very soon, and remains so, albeit at a lower level than for the standard case. From the two firms resulting from antitrust intervention one will emerge again as a monopolist, because it will benefit from increasing returns and lock ins at the demand level.

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<sup>6</sup> In a simulation, we have halved the monopolists in two but have maintained the overall endogenous bandwagon effect to one of the two new firms. Of course, the firm that have the bandwagon effect very rapidly regain a monopolistic position. This interesting result points to the fact that an antitrust intervention that aims just to break in two the R-D and the size of the monopolist, without paying attention to bandwagon effects in a market with high lock ins, is doomed to sure failure.

<sup>7</sup> In another set of simulations, we have created two new firms with exactly the same trajectory. Results do not differ from the new random trajectory case.

In the case of not immediate AA intervention (5 years), all the firms have already entered the market but they are still small in terms of size. The break up of the largest firm has the effect of making firms more similar in terms of size and resources, so that the emergence of a monopolist takes more time and the Herfindahl index reaches at the end of the simulation a medium to high level (between .6 and .7). On the contrary if the AA intervenes late (10years), the monopolist has already reached a certain size and the two new firms resulting from the intervention are already rather large with respect to the other competitors: therefore, one of the two new large firms will gain the leadership and the market will tend toward concentration, with a final level of the Herfindahl index higher than in the previous case. Finally, if the intervention occurs too late (20 years) the market will be divided into two oligopolists, which will not profit any more from the possibility of gaining market leadership because increasing returns are limited (technological opportunities are almost all depleted).

These results show the relevance of the timing of the intervention in dynamic markets. It makes a big difference whether AA intervenes too early or too late. In dynamic markets, it is important to consider whether all the potential players have already entered the market or not, firms are of small size or large size, and increasing returns have started to fade away. In case AA intervenes too early and increasing returns are still quite high, after the intervention the few players in the market generate a situation quite similar to the initial one. On the contrary, if AA intervenes too late, with limited increasing returns, the market will remain divided between two large firms.



Another interesting result of our model is the effect on the second market (PC) of an antitrust intervention in the first market (mainframes). As one can see from Table 2, as a consequence of the AA intervention in the first market, the level of concentration in the second market decreases. The reasons are basically two. When antitrust acts very early or early, and large mainframe firms are able to regenerate their advantages, two mainframe firms instead of one diversify in the PC market: the market leader and a second firm that has gained some considerable market share. Thus the PC market will be shared by a greater number of large firms, both new microprocessor firms and mainframes firms, and concentration will decrease. In case antitrust acts too late, only one firm will diversify in the other market as in the standard case. Its size however will be very small and the overall level of concentration in the PC market will decrease.

The trends in performance and prices (not reported here) do not show significant differences over time between the standard case and the antitrust interventions. Here static efficiency considerations related to the breaking of the monopolist allow for lower prices (due to the lower mark-up). However static considerations are compensated by a more limited increase in cheapness (or moving down the learning curve) and in performance due to the smaller size and the reduced R-D budget.

Finally, we have tested the effects of antitrust when one of the two sources of increasing returns characterizing the mainframe segment - lock-ins at the demand level - is not present (Table 3). In order to do that we have put the exponent on market share equal to zero in the demand equation. In this case the Herfindahl index in mainframes decreases, although not

significantly, because of the working of the effects of increasing returns on the R-D side. Interestingly enough, antitrust effects are significant and show a similar pattern (although at a lower level) as the ones in Table 1, with one difference. Once broken, in most case concentration tends to remain at the same level and not to pick up again, as in the case with demand lock-ins.

## **5.2. Entry support**

In our model the support for entry with the aim of increasing the degree of contestability and variety in the market is done in three broad ways. The first concerns the support for the exploration (pre-market) phase of existing firms; the second the support of small firms in the post entry phase; the third the increase in the number of firms in the market

### *a. Support for the exploration by firms*

First, government policy may support exploration. In our runs, support is given first to all first generation (transistors) firms (six in total) or only to firms with a small budget and later to all second generation (microprocessor) firms (twenty in total) or only to firms with a small budget. Total support is calculated in terms of share of the total initial budget of firms<sup>8</sup>. In this case 30% of the total initial budget of firms is divided among either all firms or the smaller ones. To each firm a share proportional to its budget is assigned.

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<sup>8</sup> In a series of runs the government supports firms' R-D expenditures instead of the budget. Results have not changed significantly.

Results show that, as far as concentration is concerned, no major difference with the standard case exist for the mainframe market (which remain highly concentrated). (see Table 4, where only the support for the exploration of small firms is shown). For the second generation firms, exploration support increases the entry of microprocessor firms into the mainframe market (with no much effect on the concentration level in that market). However the greater number of (microprocessor) mainframes firms now leads to a greater number of diversifiers into the PC market. Thus the Herfindahl in PC market decreases because of that (Table 5).

*b. Support for the post-entry survival of new small firms*

An alternative policy may be related to the support of new firms that just entered the market and that may lack resources and capabilities. The government may support either all firms except the leader or only the small firms (in Tables 4 and 5 we have shown only this second case). Again, 30% of the total initial budget of firms is distributed among the entrants. The total support is again proportional to its size in terms of market share. The government gives half of the budget in the first quarter of the first year, then  $\frac{1}{4}$  of support in the first quarter of the second year and the last  $\frac{1}{4}$  in the first quarter of the second year.

This type of policy is totally ineffective in mainframes: concentration does not decrease (see Table 4). The explanation is that in this case support is given to firms that were already in the market and losing. Given the strong increasing returns in the market, this is not enough to

counterbalance the dominance of the leader. In the PC market, concentration is again lower than in the standard case, because of the greater number of diversifying firms from the mainframe market.

*c. Support for the creation of new firms*

Third, a set of policies may concern the support for the creation of totally new firms (in the form of public funding of new risky initiatives), in order to increase competition and the variety of approaches and trajectories. Here again the same amount of money (30% of the total initial budget of firms) is given to two firms, without the requirement to be given back to the venture capitalists as in the standard case.

As Table 4 shows, the creation of two new firms in mainframes decreases somewhat the concentration in the mainframe market. The major effects however are on the PC market (see Table 5). The support to the two new microprocessor firms is a significant one: the initial budget of the 20 microprocessor firms is concentrated in two new large firms. Thus initially the Herfindahl index in the PC market rises. It then decreases and goes to a level even lower than the standard one, when the greater number of diversifying mainframe firms enters the PC market.

*d. Alternative runs on antitrust and entry support policies*

Given the unsatisfactory results of antitrust and entry support policies in terms of reducing concentration in the mainframe market, other types of simulations have been run.

The first set of simulations regards policies that aim to *greatly increase the number of new entrants*, in order to increase the variety of approaches.. Thus the simulation keeps the same amount of support (30% of the total initial budget) but increases the number of firms created with that support (4 or 6 transistor firms). Results (not reported here) show no change in concentration from the standard case.

Also the *coupling of the two policies* (antitrust and entry support) is not more successful than the use of a single type of policy. In fact in a second set of simulations, we have tested an antitrust intervention coupled with the creation of new firms or the support of new entrants. Results (not reported here) do not show major differences with the cases discussed above.

In a third group of simulations we have envisaged an *exceptionally big intervention*, reaching 100% of the total initial budget of firms (instead of 30%). In one set of simulation runs we studied the effect of a support of the creation of only 6 new transistor firms. In a second set of runs, support was given to 6 new transistor firms and 20 new microprocessor firms. Results (Table 6 and 7) show some decrease in the Hefindahl index in Mainframes, and a considerable decrease in the Herfindahl index in PC.

Finally, we have explored the role of policy in an environment *with less strong increasing returns*. We have maintained increasing returns at the R-D level, but not at the demand level in the mainframe market, by setting the exponent of the market share in the demand equation equal to zero. As one could imagine, the standard simulation shows a lower level of concentration in the mainframe market. Then we have analyzed the effects of the same type of policy interventions discussed above (support of 30% of the total initial budget). Results in Tables 8 and 9 show some reductions in the concentration in mainframes and PC markets. These reductions are not considerable however. Finally, we have introduced the strong type of intervention (support of 100% of the total initial budget for the creation of several new firms) just discussed above. In this case, the runs regarding the policy interventions show a much lower level of concentration (see Tables 6 and 7). In addition, policies in the mainframe market are more effective in decreasing the level of concentration than in the standard case of strong increasing returns. While significantly diminished however, concentration does not go below 0.4, even in the case of 6 new transistor firms and 20 microprocessor firms.

### **5.3. Public procurement of new products**

The government may act also as a customer who likes experimenting new technologies in established markets and therefore likes buying those products that incorporate the new technology. The government may buy totally new products not deterred from that experimentation simply because the quality of the new products is not up to that which they had been buying.

In our simulations, the government buys the new microprocessor based mainframes and acts as a large group of customers (30% of the market) who likes experimenting and buy products with the new technology. In this case the new microprocessor technology takes off rapidly, both in terms of new firms producing mainframes with the new technology and of established firms eventually adopting the new technology. But the new firms with the new technology are also able to take a dominant position in the market, and concentration in the mainframe market is significantly reduced. (see Table 6)

## **6. CONCLUSIONS**

The results of the simulations suggest some rather “provocative” conclusions. First, in strongly cumulative markets, where there are strong dynamic increasing returns, there is obviously a strong tendency towards concentration and some sort of “natural monopoly”. Our main result is that it is extremely difficult to contrast this tendency. In most of our simulations, policy interventions are ineffective in significantly modifying the degree of concentration. Only very big and focused interventions have a chance to be effective. Even when one source of increasing returns is taken away, concentration and a market leader emerge and policy intervention, albeit more successful than in the other case, is not able to break down the dominant firm and to significantly reduce concentration. Only policies of public procurement in which the government plays the role of experimental user constitutes a fundamental mechanism allowing the growth and survival of new firms with new promising technologies that would have otherwise faced difficult time in a different context.

Second, the reason of this “policy ineffectiveness” of antitrust and entry support policies lies in the strongly cumulative nature of the market. Small initial advantages tend to grow bigger over time and catching up is almost impossible. Leaders do not only have a “static” advantage: they run faster than laggards. Thus, policies of the kind of antitrust and entry support are somehow designed to “leveling the playing field”. But this is not sufficient. In order to get results, some form of “positive discrimination” may be necessary . That is to say, policies should make competitors able to run (much) faster than the monopolist, and not just remove static disadvantages. This is what public procurement in favour of highly innovative products (thus having a high potential for improvement with respect to existing products) does.

Third, our simulations suggest that there is actually almost no difference in terms of technological progress and prices between more concentrated and more competitive situations. In our model, the classical Schumpeterian trade-off does not practically exist. In terms of our (admittedly extremely rough) measures of “welfare”, there are no specific reasons to favor monopoly or competition. This does not necessarily imply that monopoly should not be contrasted. If anything, the implication might be the opposite. We should not be too worried to contrast monopoly on the basis of the “Schumpeterian trade-off”.

This is even more the case, if competition had additional virtues. For example, one might dislike monopoly on grounds different from purely “efficiency” consideration , but simply on more political bases: large concentrations of power are not desirable in a democratic society.



Closer to the nature of this paper – and obviously in an evolutionary perspective - one of the main virtues of competition is likely to reside in its ability to generate novelty, e.g. entirely new products or processes or major technological discontinuities. In its present form, our model captures it through the role played by public procurement targeted to products embodying a totally new technology and supplied by firms that enter the mainframe market on the basis of the technological discontinuity associated to the appearance of microprocessors. In this case public policy is able to affect market structure and significantly decrease concentration.

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